Travel Time Cost Surface Model (TTCSM)

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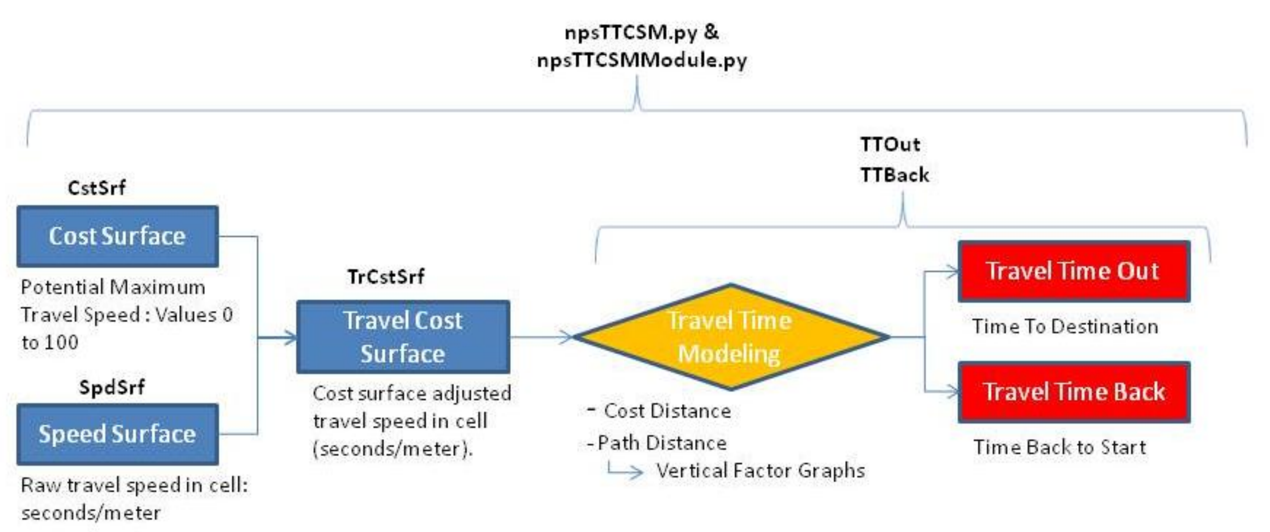
Travel Time Modeling:

The TTCSM is a linear model consisting of one master script and five main modules which generate: a cost surface, a speed surface, a travel cost surface, and travel time out and travel time back calculations. A schematic of the TTCSM model is given in Figure 1.

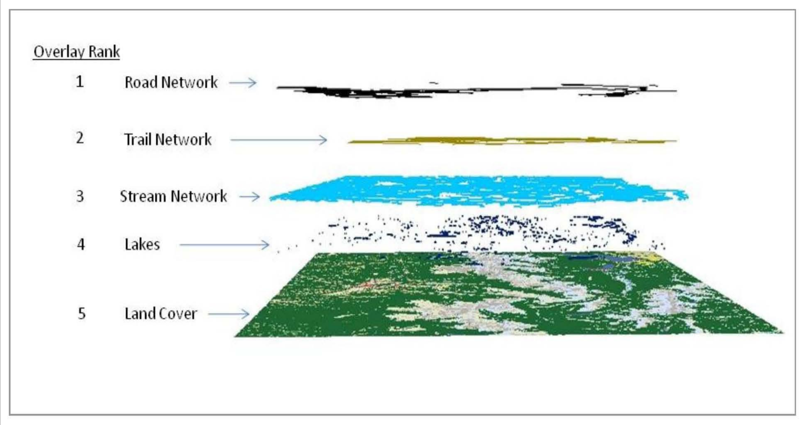
Figure 1. TTCSM Conceptual Schematic.



Cost Surface:

Developing a representative cost surface model is the first step in the TTCSM process. The **cost surface** represents the amount of travel speed resistance or impedance which is encountered when crossing through a cell. The cost surface model is a function of the variables used to define the user and park specific travel costs when traveling through the landscape.

Figure 2. Example Cost Surface Overlay Data Layers and Overlay Ranking.



Cost surface generation is accomplished in a simple overlay manner, where all input layers are ranked and subsequently overlaid (see Figure 2.). A key step in the TTCSM process is determining the data layers to use in cost surface generation, assigning a Percent of Maximum Travel Speed (PMTS) for each layer, and determining the logic by which the layers will be overlaid. PMTS is defined as the percentage of maximum speed when compared to a travel time while walking on a smooth, cement path.

For each input variable travel cost factors are incorporated into the cost surface model by assigning a PMTS value, where the PMTS values are defined as ranging between 0 and 100. Travel time increases exponentially as PMTS approaches zero (Table 1).

- A value of 0 represents an absolute barrier, indicating 0% movement relative to normal conditions.
- A value of 100 represents no impairment. Movement is 100% of what it would be without influence from a particular layer.
- A value of 50 is 50% as fast as it would be without the layer and takes twice as long to traverse.
- A value of 25 is 25% as fast as it would be without the layer and take four times as long to traverse.

Table 1. PMTS versus Travel Time.

PMTS (% of Maximum Speed	Travel Time Units
100	1
95	1.1
90	1.1
85	1.2
80	1.3
75	1.3
70	1.4
65	1.5
60	1.7
55	1.8
50	2
45	2.2
40	2.5
35	2.9
30	3.3
25	4
20	5
15	6.7
10	10
5	20
0	Indefinite (Forever)

Speed Surface:

The **speed surface** module creates a grid which defines the travel speed, in seconds per meter, at which movement within a cell occurs. The speed surface is a function of three factors, road network speed, trail speed, and hillside slope speed. After these speeds have been derived, the speed surface is generated in an overlay manner, similar to the cost surface model. The speed surface overlay order from the top layer to the base layer is 1) road network, 2) trail speed and, 3) hillside slope speed.

Speed Calculation

Potential speed along a road is determined only by the speed limit with the assumption that the vehicle is powerful enough to maintain the speed for even the steepest hills. Trail speed and hillside slope speed (seconds per meter) are determined by slope (Degrees) (Theobold, 2003; Tobler 1993) with the equation given below:

$$6 * EXP\left(-3.5 * ABS\left(TAN\left(\frac{Slope}{57.29578}\right) + 0.05\right)\right)$$

Where a trail exists, the slope is calculated to follow the contour of the trail. During speed surface generation the model assumes speed is equal (isotropic) in all directions, thus regardless of whether someone is traveling up or down hill, their speed will be the same. The influence of moving with or against gravity can be accounted for in the travel time modeling process using path distance modeling methods. This will be further discussed in the travel time path distance modeling section.

Abstract:

The travel time cost surface model (TTCSM) calculates travel time from single or multiple location(s) to other locations within a user defined area of interest (AOI). The TTCSM is designed to model travel time in national park units using readily available geospatial products such as road, trail, and stream networks, digital elevation models and land cover data to name a few. Outputs from the TTCSM are point to point specific travel time least cost paths (i.e. the modeled fastest path(s)) and raster maps in which each cell value is the modeled time required to reach the given cell from the specified starting point(s).

In order to derive useful travel time calculations, the TTCSM is intended to be dynamic in nature to accommodate user (e.g. hiker / skier / ATVer / etc.), temporal (e. g. winter / summer data collection), environmental and park specific needs. The essence of the TTCSM is deriving a meaningful travel cost surface. Travel cost is a function of the user defined and derived cost and speed surfaces. The cost surface defines the weight or impedance of traveling through a cell, while the speed surface defines the speed at which movement within the cell occurs. Speed is a function of slope, except on the road network where speed is equal to the defined road speed limit. Using the derived travel cost surface, travel time calculations are performed using either traditional cost distance or more robust path distance modeling methods.

The TTCSM is indented to be used as a tool to help NPS staff be more efficient and effective at travel time planning efforts. An essential component of this model is the ability of the user to optimize the model in order to accurately represent their park specific needs. Currently, the TTCSM is packaged as a python script requiring only basic understanding of python programming, and a moderate level of proficiency in GIS.

The SOP document and TTCSM scripts can by downloaded at http://nrinfo.nps.gov/Reference.mvc/Profile?Code=2164894.

Model Design:

After the cost and speed surface grids have been developed the speed surface is divided by the cost surface to yield the travel cost surface. The travel cost surface has the final travel speed (seconds/per meter) at which movement within a cell occurs (see Figure 3). Using the travel cost surface the last step in the TTCSM process is to calculate travel time using either cost distance or path distance least- cost path modeling.

Figure 3. Travel Cost Surface.

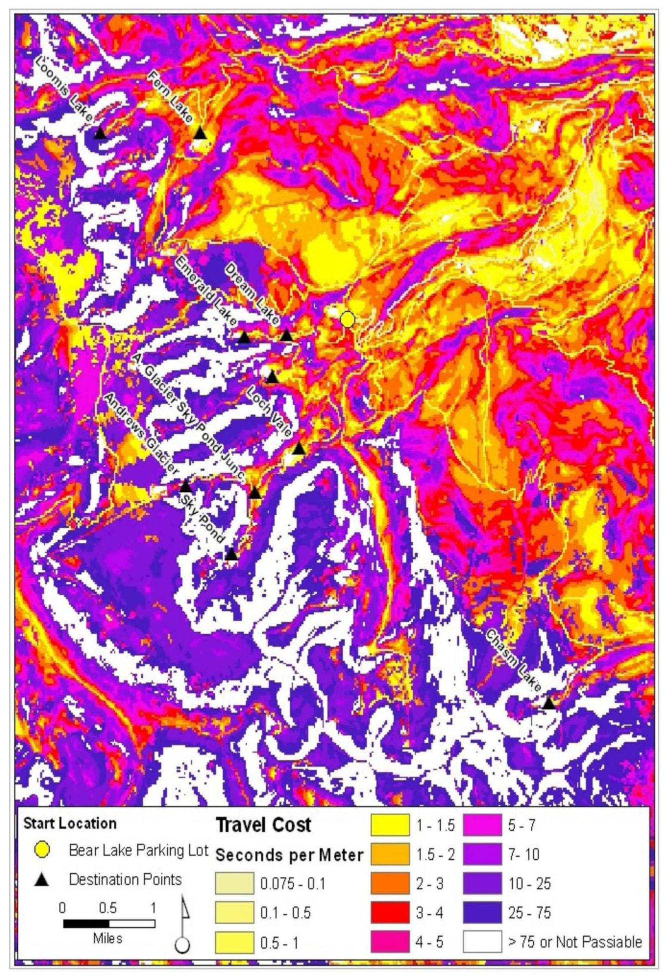
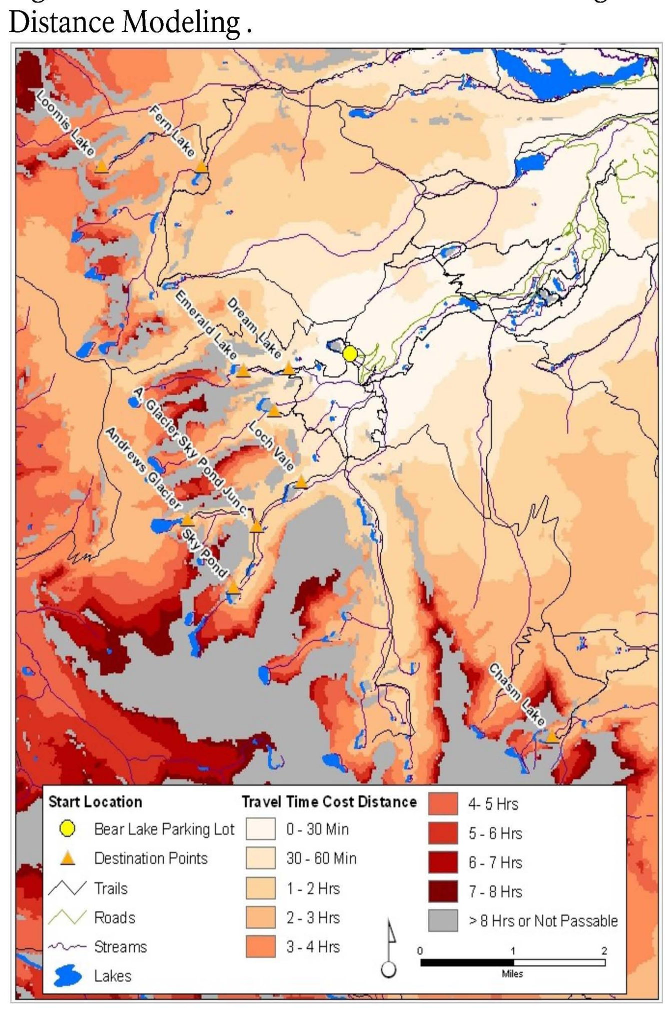


Figure 4. Travel Time Cost Surface Derived Using Cost Distance Modeling .



Cost Distance Modeling

Cost distance modeling calculates travel time using the ArcGIS Cost Distance function. Cost distance calculates the least accumulative cost required to move from the "From" source cell to the next "To" destination cell. The cost of traveling through a cell is calculated by multiplying the cost per unit distance, as defined by the travel cost surface (seconds/per meter), times the grid cell resolution and also accounting for diagonal distance when appropriate. In this manner the least accumulative travel cost is calculated from the defined starting location(s) to all other cells within the AOI. An example travel time cost surface derived using cost distance modeling is shown in Figure 4. In this example travel times were calculated from a starting location of the Bear Lake parking lot in Rocky Mountain National Park (ROMO).

Path Distance Modeling— Directionality Matters

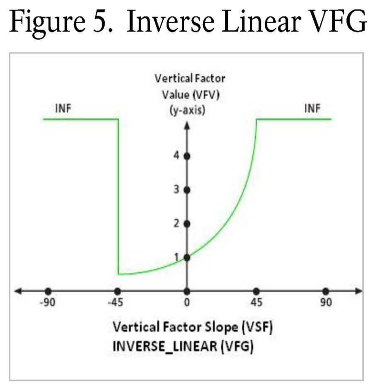
A more complex and potentially more realistic method of calculating travel time distance is to use path distance modeling with the ArcGIS Path Distance function. Path distance calculates the accumulative cost to travel over a cost surface (the travel cost surface in the TTCSM), while also compensating for the actual surface distance that must be traveled in the horizontal and vertical directions. Path distance modeling has the ability to account for the anisotropic nature of movement based on slope. Or put another way path distance modeling can account for directional differences in travel speed when traveling upslope versus down slope and vice versa.

Accounting for Directionality

In the TTCSM only the vertical factor (VF) option in the path distance function is utilized. Using a DEM as the VF raster, during least- cost path analysis the slope between the origin "From" cell and the adjacent "To" cell is calculated. Using this directionally dependent Vertical Factor Slope (VFS) value, the VFS is graphed on a VF Graph (VFG) in order to define a Vertical Factor Value (VFV). The VFV is then subsequently multiplied on the travel cost surface to yield the final VF adjusted (directionally dependent) travel cost which is encountered when moving through a cell.

To best model the influence of slope on your user specific travel speeds, path distance modeling can be performed using 9 predefined VFG's, or a custom defined VFG. The "inverse linear" VFG is shown in Figure 5.

Figure 5. Inverse Linear VFG

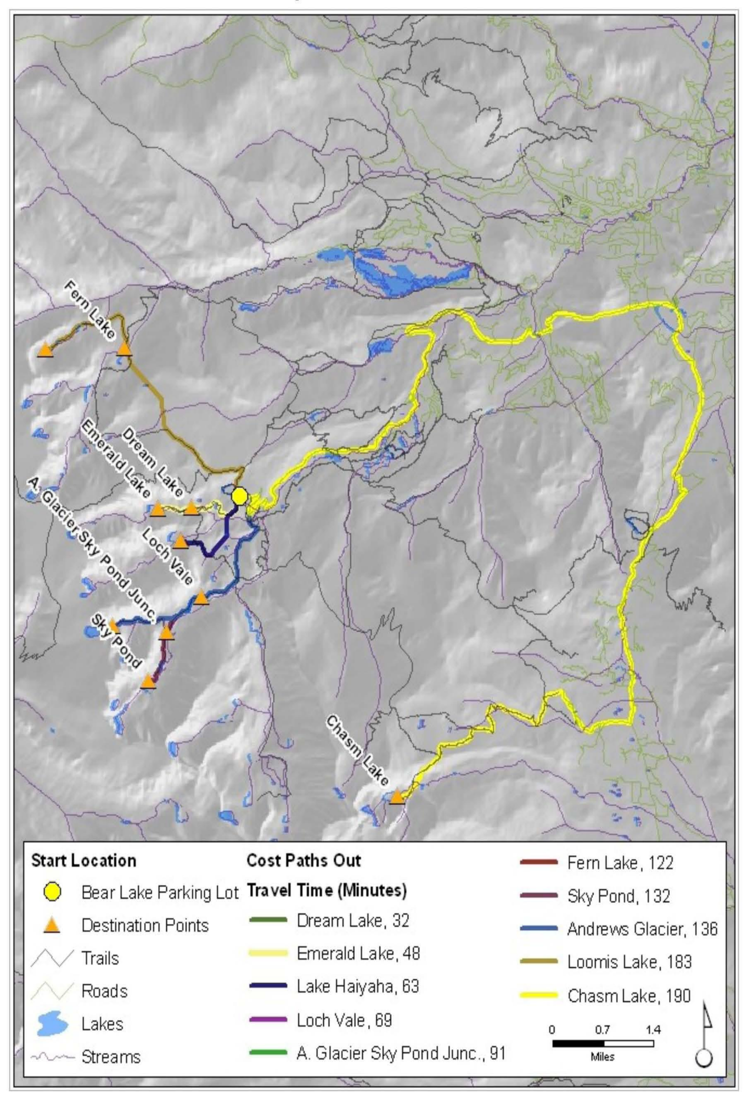


TTCSM Output:

Travel Time Least Cost Paths

Travel time least cost paths can be derived from the defined starting point(s) to each unique destination location. The destination locations are defined by a "destinations" point data layer. In addition to providing the estimated travel time to reach the destination the least cost path spatially shows the modeled least cost path. Figure 6 shows the least cost paths that were derived using path distance travel time modeling with an "inverse linear" VFG (see Figure 5). The least cost paths were calculated from the Bear Lake parking lot in ROMO, to ten destination locations within the park.

Figure 6. Travel Time Out Least Cost Paths derived using Path Distance Modeling with an inverse linear VFG.



For these same ten destinations the travel out least cost path travel times are shown for four different travel time modeling methods (Table 2). For the 10 destination locations that were selected the majority of travel would be uphill, which can be seen by the increased estimated travel time for the path distance modeling methods. The Cost Distance travel time is less than all the path distance estimates because the model doesn't account for difference in travel speed due to slope directionality.

Table 2. Travel out least cost path travel times for four different travel time modeling methods.

	Travel Time (Minutes) By Modeling Method			
Destination	Cost Distance	Path Distance Linear	Path Distance Inverse Linear	Path Distance Custom Table
Dream Lake	26	28	32	36
Emerald Lake	41	44	48	53
Fern Lake	119	120	122	148
Loomis Lake	158	165	183	208
Lake Haiyaha	49	54	63	70
Loch Vale	55	59	69	76
Andrews Lake/Sky Pond Trail Junction	76	81	91	100
Andrews Glacier	104	113	136	147
Sky Pond	107	115	132	147
Chasm Lake	162	173	190	214

Table 3. Travel out, travel back and round trip travel time as estimated using an inverse linear path distance travel time model.

	Travel Time (Minutes)		
Destination	Out Time	Back Time	Round Trip
Dream Lake	32	23	55
Emerald Lake	48	37	85
Lake Haiyaha	63	42	105
Loch Vale	69	49	118
A. Glacier Sky Pond Junc.	91	69	160
Fern Lake	122	114	236
Sky Pond	132	94	226
Andrews Glacier	136	91	227
Loomis Lake	183	150	333
Chasm Lake	190	166	356

Round Trip Option

The TTCSM can be used to model either one way or round trip (out and back) travel times. Depending upon the terrain in the AOI, the desired destination, and the mode of travel, travel out and travel back times can be substantially different. As was discussed in the path distance modeling section, if path distance modeling is used then travel speed differences related to upslope versus down slope travel are incorporated into the time estimate.

When path distance modeling is selected separate travel out and travel back time estimates should be performed in order to account for the time differences associated with each direction of travel. If cost distance modeling is used then the travel out and travel back times will be the same due to the isotropic nature of the model. Travel out, travel back and round trip travel times are shown for the 10 selected destinations in ROMO, starting from the Bear Lake parking lot in Table 3.

Running TTCSM:

The TTCSM has been developed in the Python 2.5.1 environment and consists of one master scripts (npsTTCSM.py) which syncs up to five individual modules housed in the npsTTSCMModule.py script. The CstSrf, SpdSrf and TrCstSrf modules (Fig.1) derive the cost surface, speed surface and travel cost surface grids respectively. Lastly the TTOut and TTBack modules perform the travel out and travel back travel time modeling processes. The TTCSM is designed to run in the Python scripting language on a computer with ArcGIS 9.3 functionality.

Required GIS data layers to run the TTCSM.

Data Layer	TTCSM Variable Name	Description
Start Location(s)	**startLocation**	Feature class with the defined starting point(s) for travel time calculations.
Road Network	**roadsData**	Road Network Feature Class, with 'PMTS' and 'Velocity' fields, for the Cost Surface and Speed Surface modules respectively.
Trail Network	**trailsData**	Trail Network Feature Class, with a 'PMTS' field, for the Cost Surface module.
Digital Elevation Model	**DEM**	Digital Elevation Model.
Cost Surface Table	**costSurfaceTable**	Table used to define the cost surface factors, the PMTS for each factor, and the overlay logic. Table should be a comma delimited text file.
Destinations	**Destinations**	Feature class with the desired "To" locations from which to calculate travel time least cost paths.

Works Cited

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